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STATE-OF-THE-ART MANUFACTURING TECHNOLOGIES OF PEMFC COMPONENTS

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Abstract

Description and analysis of membrane electrode assembly and different manufacturing processes of Proton Electron Membrane has been made. Efforts were made to explain the types of assembly and manufacturing methods. Finding innovative ways to fabricate PEM fuel cell components, which affords mass production at lower operating cost, is one of the major threats to its commercialisation. Additive manufacturing techniques are seen as efficient and fast manufacturing methods that builds up components layer-by-layer in three dimensions, rather than conventional subtractive manufacturing techniques. This helps to reducing the overall cost, manufacturing time and wastage. The major aim of this work is to help people working with PEM fuel cells make informed decision regarding the selection of material and the choice of process. Choosing the right type of assembly and manufacturing method can go a long way to reduce the cost of production and durability.

Keywords: MEA, manufacturing, PEM fuel cell, fabrication

1 INTRODUCTION

Considering the current challenges facing the environment and meeting the required energy target, PEM fuel cells, being a sustainable energy [1,2] are realistic solutions. With events all around the world it is established that the need for fuel cells as an alternative energy is at the peak. This is because continued reliance on fossil fuel will only make the world a difficult place to live in due to high level of pollution [3–7]. Fuel cells, when converting fuels into energy, performs at efficiencies greater than the conventional combustion technologies [8]. They have been tested in some areas and have performed. These areas include transportation, powering stationary equipment and in the production of some small devices like cell phones, laptops, video recorders etc. Presently they have been used in the production of automobiles such as cars and buses; they have also been used in making stationary equipment like a power plant and a lot of portable applications. They have been used in combination with other clean energy sources, an example is solar energy[9].

Although the PEM fuel cell was invented by T. Grubb & L. Niedrach at GE in the 1960s, many researches which led to this landmark achievement started in the 1800s. The first demonstration of fuel cell was carried out by Sir William Grove in 1836. Presently there are various types of researches on different types of fuels cells with approximately 90% of them focusing on PEM fuel cells. Therefore over the years a lot of success has been recorded towards the development of PEM fuel cells.

Fuel cell can be defined as a device that converts chemical energy into electrical energy in a controlled reaction where temperature is kept constant. The fuel cell has often been compared with a battery, the different being that while the reactants and electrolyte in a battery is sealed into the battery the fuel cell is supplied with fresh reactants. These reactants were being referred to as fuels. Examples of fuels used by fuel cells are hydrogen, oxygen, methanol, gasoline etc. For PEM (Proton Electrolyte Membrane), the reactants are hydrogen and oxygen.

Most researches on fuel cells now focus on Proton-electrolyte-membrane fuel cells (PEMFC). And in majority of this work, issues about adopting the technology have mostly been dominated by its effects on the environment and cost[10]. The PEM fuel cell, with water as its bye-product, has very low pollution emission. It is believed that continuous researches on materials and component will deliver the development of a more efficient system with a reduced cost. Work done on membrane electrode assembly and manufacturing can have a great effect on cost, performance and the shell life of the fuel cell. Figure 1 below shows the diagram of a PEM fuel cell and figure 2 shows a planar diagram of a PEM fuel cell. Detailed analysis of the entire different component that made up the fuel cell in figure 1 is analysed in figure 2.

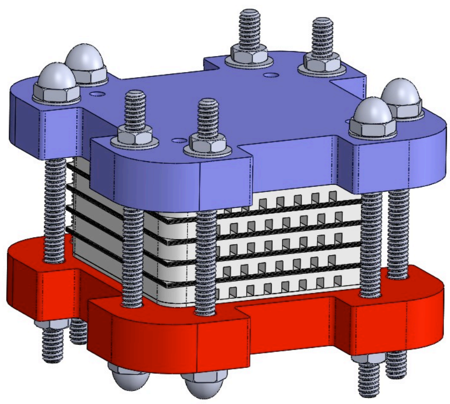

Figure 1: Diagram of a pem fuel cell

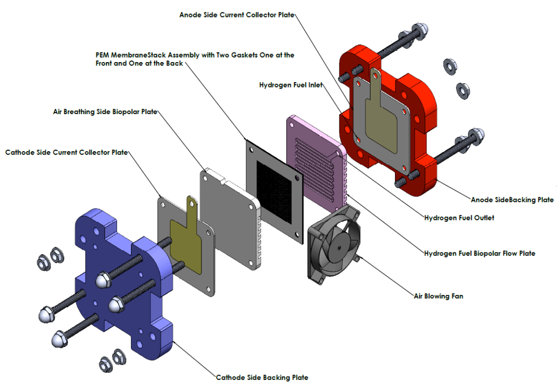

Figure 2: Planar diagram of a PEM fuel cell

2 MEMBRANE ELECTRODE ASSEMBLY

2.1 Types of Assembly

Fundamentally there are two fabrication methods to assemble the MEA for PEMFC and are distinguished on the basis on where the catalyst ink is deposited to make the electrode. The first method is by deposition of the catalyst layer on a porous GDL such as carbon paper, followed by hot pressing it with the membrane to make the membrane. This method is commonly known as catalyst-coated substrate (CCS). In the second method, the catalyst layer is deposited directly onto the membrane; this method is referred to as catalyst-coated membrane (CCM). Figure 3 illustrates the two methods.

In additional to the second method, an intermediate step has been introduced to overcome issues of membrane swelling and wrinkling due to the direct contact with catalyst ink throughout the fabrication process.

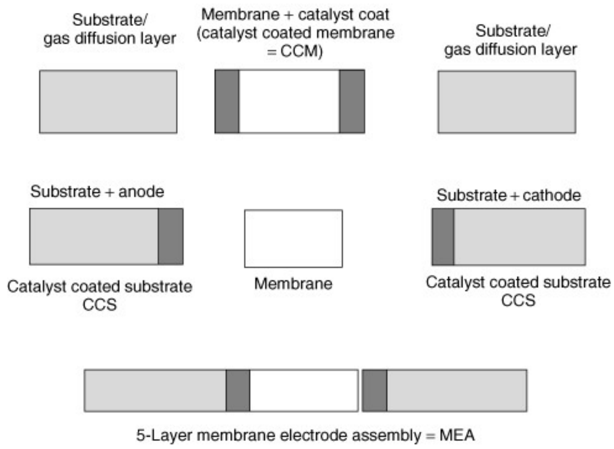

Figure 2: MEA's CCM and CCS fabrication methods

This step is known as Decal Method Transfer (DMT) and it involves the lamination of the catalyst layer onto the membrane through a temporary substrate such as Teflon film by pressing at a high temperature 210-250^{o}C [11]. Thanaslip [12] investigated the performance of PEMFC at the three fabrication methods and reported that DMT type provided the highest cell performance, followed by MEA's made by CCM, and the lowest performance MEA's made by CCS. This is due to the fact that some of the Nano-structured catalyst particles protrude in GDL pores, leading to the reduction of their catalytic activation.

2.2 Membrane Processing

The polymer electrolyte membrane is usually procured in roll form as an end product from its manufacturer, and the only processing steps required on it is to boil it in hydrogen peroxide, dilute sulphuric acid and water. These steps serve to clean the membrane, and to ensure that it is protonated [13].

2.3 Diffusion Layer Processing

The gas diffusion layer is composed of two layers, the Macro-porous layer and the Micro-porous layer. The Macro-porous layer is fundamentally the section where the diffusion media has been treated with a hydrophobic agent (PTFE). Hydrophobicity is a crucial requirement to avoid flooding of water in the diffusion media channels. The precursor for the diffusion media is generally either carbon cloth or carbon paper, and the macro-porous layer is formed by applying Teflon solution onto the substrate. The microporous layer which helps in managing the water content of the MEA [14], is a far thinner layer made by coating the macro-porous layer that is mixed with carbon black and PTFE. Content of PTFE in both layers is also important, as it directly change the porosity and hydrophobicity of the diffusion media which in turn affects the reactants mass transport to the catalyst layers [15]. The method in which this mixture is deposited is similar to how the electrode layers are formed, thus the same processes can be used to fabricate the micro-porous layer.

2.4 Catalyst Ink Preparation

The catalyst ink, a liquid precursor of the catalyst layer, is usually composed of the following components as reported by Wilson [6]:

- Catalyst (platinum, platinum supported)
- Electrolyte/inomer (PFSA or other protonated inomers)
- Solvent (deionised water, glycerol)
- Additive (dispersing agents)

Wilson [16] stated that the first consideration when preparing the ink is the composition of each component, followed by the compound's viscosity and the surface tension.

3 STATE-OF-THE-ART MANUFACTURING METHODS

One of the challenges of the commercialisation of PEMFC is finding new and innovative ways to fabricate the different components that will enable mass production at reduced operating costs [17]. Additive manufacturing (AM), better known as 3D printing is perceived as a way to develop cost effective PEMFC. The following graph illustrates some the AM technologies based on the form of the starting material.

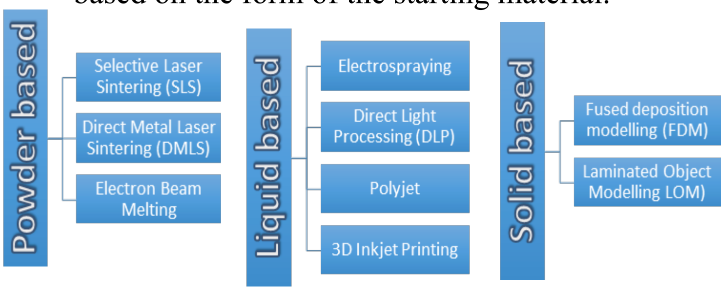

Figure 3: AM manufacturing technologies

3.1 3D Inkjet Printing

Recently there has been a lot of interest with respect to the inkjet printing technology for manufacturing the catalyst layers onto the MEA's. Towne et al. [18] investigated the possibility of manufacturing the GDE (Gas Diffusion Electrode) for PEMFC MEA using off the shelf inkjet printing equipment. Although they have successfully shown the high capabilities of the process, there were few concerns with the process. The drop size, jetting velocity, print head speed, number of nozzles, distance between nozzles, and platen speed cannot be manually controlled. Furthermore, the nozzles of the print heads are in the range 10-20 μm which are very small in size. This causes to coagulation of droplets in the print heads. Thus, to avoid these problems, the catalyst powder has to be ground fine using high cost equipment such as ball mills etc. The catalyst powder size must be around 100-500 nm for the ink droplets to not coagulate in the print heads. This in turn results in an increase in the cost of the catalyst powders.

When comparing this process with conventional processes such as hand painting method. The former process has demonstrated a better quality control, and less assembly time, which was 30 seconds against 5 minutes.

3.2 Fused Deposition Modelling

Fused Deposition Modelling is an additive fabrication technology which constructs superior rapid prototypes from 3D CAD data where in a thermo plastic material is extruded in the form of beads layer by layer using a temperature controlled head which is controlled by Computer Aided Manufacturing (CAM) software [19]. The thermo plastic materials used in FDM process have good stability and durability of the mechanical properties over time; they have high heat resistance and also produce smooth parts with all the finest details intact.

Chen [21] used this technology to manufacture miniature fuel stacks in a planner array form. For the fabrication of miniature fuel cell it is required to have pinpoint precision, as the aim of this type of fuel cell is to have high power density. Alternative conventional methods include Micro-Electro-Mechanical MEM processes and CNC machining process. Chen Have compared the two conventional processes with FDM in the fabrication of the flow field geometry and reported that more precision was achieved with FDM and it required less time which was 1 hour compared to 2 hours and 20 hours for CNC and MEM's respectively

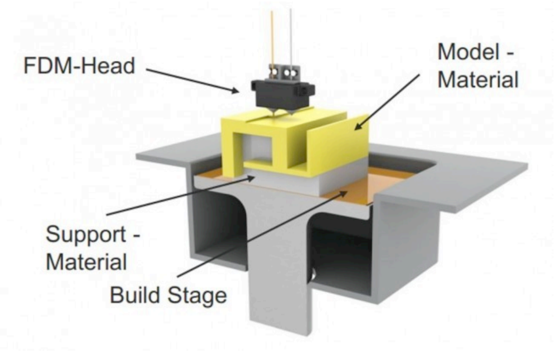

Figure 4: FDM process [20]

3.3 Selective laser sintering

The objects in Laser Sintering (SLS) manufacturing process are made by printing powder materials, most commonly plastics such as polyamide, polyethylene etc. The laser's energy is directed to the bed surface and thus used to build up a 3D structure in a layer-wise routine, layer by layer. This process is particularly suited for bipolar plate component as 316L and other stainless steels are frequently used to produce net shape products that are 98 to 99% dense. The process needs to generate a 3D CAD model of the object to be printed and then converted into the compatible file format for uploading to the SLS machine. The process offers several advantages for the development of bipolar plates in comparison to conventional method Compression Molding (CM). It offers the ability to build complex flow fields and consumes less time and financial resources. A number of authors [22] have investigated the fabrication of graphite composite bipolar plate using this technology. Components made from SLS have proven to have lower electrical conductivity, and more porous. It's therefore required to post process the components to improve conductivity and obtain gas impermeability which are essential requirements for bipolar plates materials. One of the treatments that can be used to improve conductivity of bipolar plates is liquid phenolic infiltration, which was shown by Chen and the treatment was able to boost conductivity by 35% [23]. Another disadvantage of the process is the roughness of the surface finish produced, which is highly dependant on the size of powder particles. This can be enhanced by a surface re-melting process as shown by Yesa [24].

3.4 Direct metal laser sintering (DMLS)

This process works in the same manner as SLS in terms of using a laser as a way to consolidate powder, except for using a metal powder as source of material. With DMLS, the metal powder, and the fluxing agent, is fully melted by the scanning of a focused laser beam and fuse it into a solid form with properties of the original material. After each layer is completed, a blade adds a new layer and repeats the process until the last metal part is formed as illustrated in figure 6.

Removing the polymer binder prevents the burn off and infiltration steps, and it provide a 95% dense steel component compared to roughly 70% density with SLS. Furthermore leftover powder can be used again, which thus decreases waste level. DMLS has different requirements for the design of parts, as well as special positioning requirements of the parts on the bed.

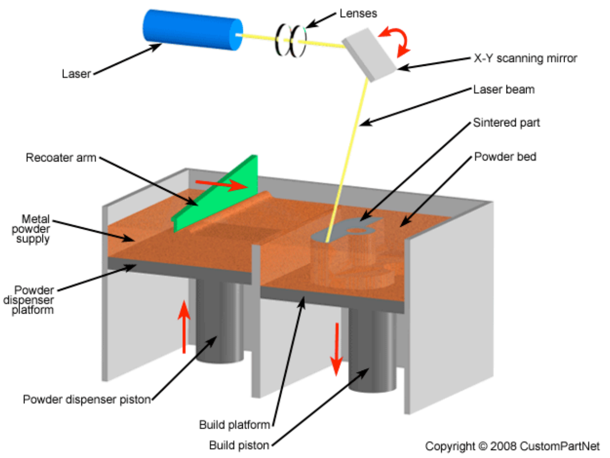

Figure 5: DMLS Process [25]

4 CONCLUSION

Attempt has been made to discuss membrane electrode assembly and the additive technologies used to manufacture PEM fuel cell components. The best manufacturing method to be used is determined based on the starting material. Also finding new and innovative ways to fabricate the different components could enable mass production at reduced operation cost.

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